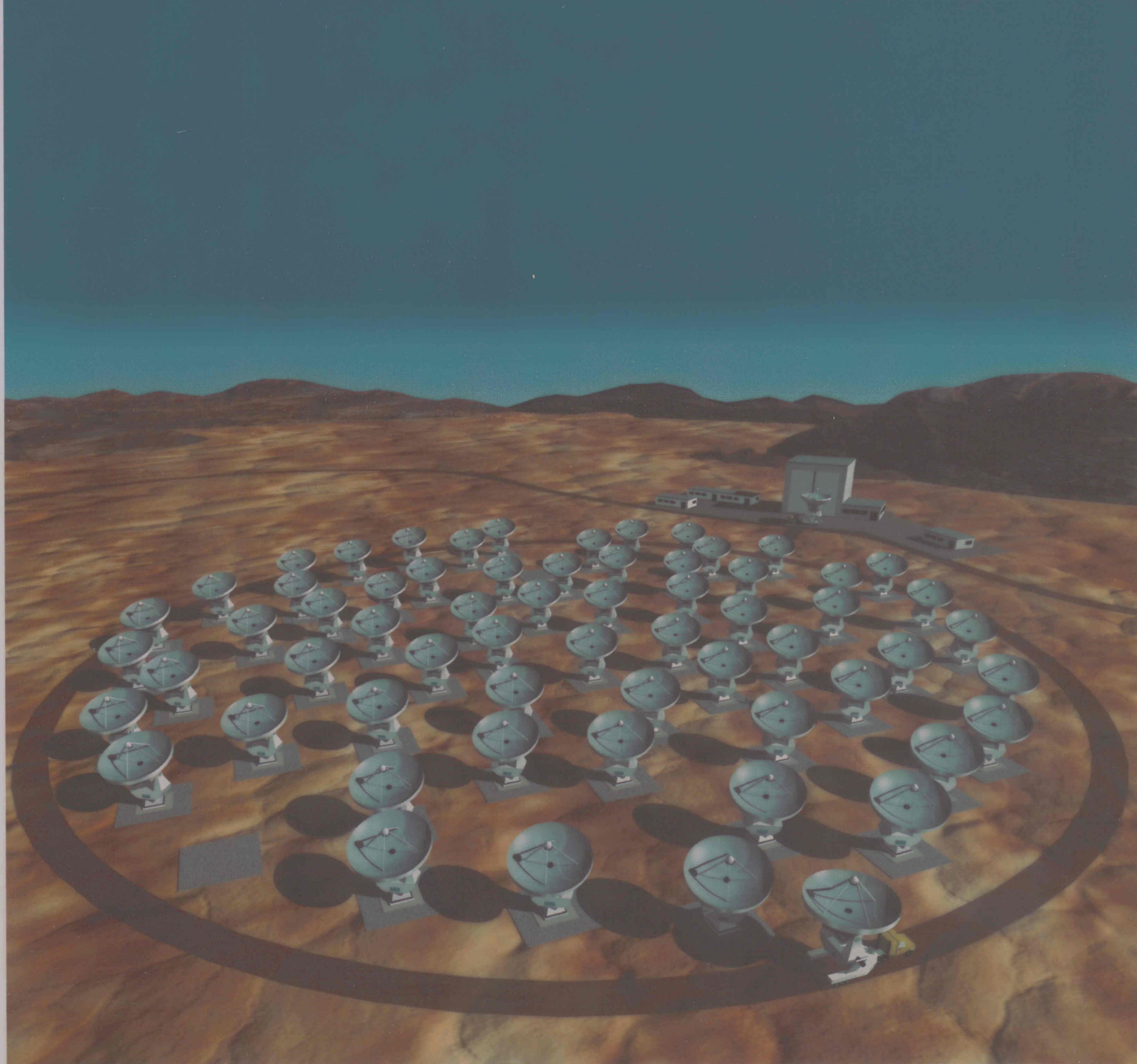
ALMA Project Plan

April 2002



Executive Summary

Executive Summary

The Project Plan for construction of the Atacama Large Millimeter Array is encompassed in the Annexes to the *Agreement Concerning the Joint Construction and Operation of the Atacama Large Millimeter Array (ALMA)* between the U.S. National Science Foundation and the Canadian National Research Council, and the European Southern Observatory. Those Annexes are presented here; they include:

Annex A, the ALMA Project Description

Annex B, the ALMA Science Requirements

Annex C, the ALMA Work Breakdown Structure, Schedule of Values and Assignment of Deliverables

Annex D, the Project Time Schedule

Annex I, the ALMA Organization and Management Plan

The ALMA Project Plan is built around the *Guiding Principles* for the Project as set forth in Article 2 of the Agreement. In particular, the Project is established by two Parties with efforts and benefits equally divided between the two. The construction is assumed to begin in calendar year 2002 and to have all the Project hardware and software delivered by the end of 2011.

The Plan fully incorporates in its planning the anticipated funding schedules of the two Parties. Owing to differences in those schedules which reflect a more accelerated funding on the North American side, many of the tasks for which early deliverables are required are the responsibility of North America. Conversely, many of the tasks for which deliverables are needed late in the Project are the responsibility of ESO. Such a division of responsibility was achievable while fully preserving the goal of equity between the two Parties.

The Project schedule is constructed around the time needed for completion of the individual tasks in the Project work breakdown structure with the understanding that some, but not all, of those tasks are directly dependent on the available resources. Consistent assumptions have been made throughout. The process by which procurement of the production run of 64 antennas is concluded presents special concern for the schedule. Delivery of the production antennas is the pacing task for the construction project. However, award of the contract for those antennas is serially dependent on evaluation of the prototype antennas; hence any delay in the delivery of the prototypes or in their evaluation will introduce delay in the project schedule, and with that delay comes a cost penalty. The ALMA Project schedule presented in Annex D addresses this risk area by means of a decision point, at a fixed date in 2003, at which an informed decision will be made.

Annex A

ANNEX A

Project Description

Draft: 4 April 2002

The material in this document has not been approved

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1 PROJECT OVERVIEW

The Atacama Large Millimeter Array (ALMA) is a revolutionary instrument in its scientific concept, in its engineering design, and in its organization as a global scientific endeavor. ALMA will provide scientists with precise images of galaxies in formation seen as they were twelve billion years ago; it will reveal the chemical composition of heretofore unknown stars and planets still in their formative process; and it will provide an accurate census of the size and motion of the icy fragments left over from the formation of our own solar system that are now orbiting beyond the planet Neptune. These science objectives, and many hundreds more, are made possible owing to the design concept of ALMA that combines the imaging clarity of detail provided by a 64-antenna interferometric array together with the brightness sensitivity of a single dish antenna.

The challenges of engineering the unique ALMA telescope begin with the need for the telescope to operate in the thin, dry air found only at elevations high in the Earth's atmosphere where the *light* at millimeter and submillimeter wavelengths from cosmic sources penetrates to the ground. ALMA will be sited in the Altiplano of northern Chile at an elevation of 5000 meters (16,500 feet) above sea level. The ALMA site is the highest, permanent, astronomical observing site in the world. On this remote site superconducting receivers that are cryogenically cooled to less than 4 degrees above absolute zero will operate on each the 64 12-meter diameter ALMA antennas. The signals from these receivers will be digitized and transmitted to a central processing facility where they are combined and processed at a sustained rate greater than 10^{16} operations per second. As an engineering project, ALMA is a concert of 64 precisely-tuned mechanical structures each weighing more than 80 tons, superconducting electronics cryogenically cooled, and optical transmission of terabit data rates--all operating together, continuously, on a site high in the Andes mountains.

2 PROJECT TECHNICAL DELIVERABLES

The ALMA construction Project will deliver an antenna array capable of meeting the scientific requirements as summarized in Annex B. A tabular summary of the technical description of ALMA as derived from those science requirements is presented in Table 1. A brief description of the key elements is included here.

ALMA Technical Summary

Array	
Number of Antennas	64
Total Collecting Area (ND^2)	7238 m^2
Total Collecting Length (ND)	768 m
Angular Resolution	$0''.2\ \lambda$ (mm)/baseline (km)
Array Configurations	
Compact: Filled	150 m
Intermediate (2)	500 m, 1500 m
Precision Imaging	4.5 km
Highest Resolution	14.0 km
Antennas[1]	
Diameter	12 m
Surface Accuracy	20 micrometers RMS
Pointing	$0''.6$ RSS in 9 m/s wind
Path Length Error	< 15 microns during sidereal track
Fast Switch	1.5 degrees in 1.5 seconds
Total Power	Instrumented and gain stabilized
Transportable	By vehicle with rubber tires
Receivers[2]	
84 - 119 GHz SIS	T(Rx) < 50 K
211 - 275 GHz SIS	T(Rx) < 6*h*nu/k SSB
275 - 370 GHz SIS	T(Rx) < 4*h*nu/k DSB
602 - 720 GHz SIS	T(Rx) < 5*h*nu/k DSB
Dual polarization	All frequency bands
Intermediate Frequency (IF)	
Bandwidth	8 GHz, each polarization
IF Transmission	Digital
Correlator	
Correlated baselines	2016
Bandwidth	16 GHz per antenna
Spectral Channels	4096 per IF

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[1]The antenna specifications are detailed in *Request for Proposals for a Prototype Antenna for the Millimeter Array/Large Southern Array,* dated March 30, 1999.

[2]These four frequency bands are those required on the *first-light* ALMA as specified by the joint US-European ALMA Science Advisory Committee at the committee meeting of March 11, 2000. Receivers in six additional atmospheric windows are deferred to the Project options list for support from possible unallocated Project contingency funds and future development funds.

Array Site: ALMA will be built on the Chajnantor altiplano in the Atacama Desert of northern Chile. Its approximate coordinates are 67 degrees West, 23 degrees South. The site is at an elevation of slightly over 5000 m. The site land is administered by the Chilean government office of national assets and set aside by Presidential decree as a protected region for science. Measurements made *in situ* continuously since 1995 of the atmospheric transparency and stability confirm that the site has superior conditions for millimeter-wave, and submillimeter-wave astronomy and it will meet the science requirements for the ALMA Project.

Antennas and Antenna Configurations: The sixty-four ALMA antennas each have a reflecting surface 12 meters in diameter with a parabolic cross-section. The number and size of the antennas is determined from imaging requirements; the materials used in their construction is dictated by the fact that ALMA will operate 24 hours a day and hence the antennas must maintain their performance when fully exposed to the thermal variations and wind gusts imposed by the site environment. Each antenna is fully steerable; more than 85 percent of the celestial sphere is visible from the Chajnantor site.

The antennas are all movable among prepared antenna foundations, or *stations*. Each station has a concrete foundation to support the antenna and provision for electrical power and data communications. The antennas are moved by a specially-designed *antenna transporter*. The ability to move the antennas, and hence to rearrange them on the ground, provides ALMA with the capability to match its angular resolution to the science requirements of its users. Antenna configurations as small as 150 meters in diameter (for the study of large or low brightness objects) and as large as 14 km in diameter (for the study of small, high brightness objects) are deliverables of the ALMA construction project.

Front End Electronics: Each antenna will be equipped with a receiving system, or *front end,* capable of detecting astronomical signals in four frequency bands. These are *coherent* detectors, meaning that they employ a common local oscillator signal to convert the received signal frequency to a much lower *intermediate frequency* that is subsequently transmitted to the central electronics building where it is combined with the signals from all other antennas. The local oscillator is a deliverable of the front end electronics task, but the intermediate frequency transmission and processing is a task of the *back end* subsystem. Further, each of the four frequency band *cartridges* includes two receivers operating in orthogonal senses of linear polarization so that the full polarization state of the received radiation may be measured. The receivers are based on superconducting mixers that operate at temperatures below 4 degrees K. All of the cartridges are included in a single cryogenic dewar located at the cassegrain focus.

Also at the cassegrain focus, but removed from the optical axis of the telescope, is a water vapor radiometer tuned to the 183 GHz line of terrestrial water emission. Each antenna has such a water vapor radiometer that is used to measure the column of atmospheric water above the antenna; from these measurements the phase distortion of an astronomical signal resulting from its passage through the screen of atmospheric water is determined and its deleterious effects may be removed from the measured astronomical signal.

Back End Electronics: The intermediate frequency that is output from the front end is amplified and digitized at the antenna by the back end electronics. In order to process the 2 x 8 GHz bandwidth of the intermediate frequency signal, the back end electronics subdivides that signal into four 2 GHz sub-bands for transmission to the correlator.

Correlator: The correlator is a special-purpose digital signal processor. It combines the digitized intermediate frequency signals from all the antennas pair wise; there are 2016 pairs of antennas in ALMA. Images of the astronomical source are created by Fourier inversion of these complex (phase and amplitude) data.

Computing and Software: The computing system has the task of scheduling observations on the array, controlling all the array instruments, including pointing the antennas, monitoring instrument performance, monitoring environmental parameters, managing the data flow through the back end electronics and presentation of these data to the correlator. The output of the correlator is again the responsibility of the computing task where it is processed through an image pipeline, calibration is applied, and first-look images are produced. Finally the science data and all associated calibration data, monitor data, and derived data products are archived and made available for network transfer.

The deliverables from the computing task include the software system necessary to achieve the functionality noted above and the hardware necessary to run that software and manage the data flow.

Organization: The system engineering, scientific oversight, and management necessary to coordinate the task activities of the ALMA technical team responsible for production of the ALMA technical system noted above are integral deliverables of the ALMA Project as well.

3 PROJECT PROGRAMMATIC SCOPE

3.1 Data Products

The fundamental data products from ALMA are calibrated, pipeline-processed, images. These images, together with the *uv-data* files, calibration files, and monitor information files, will be delivered in a timely manner following completion of the scheduled observing program to the astronomer who proposed the observation. All of these same data will be written to a permanent archive.

The burden this programmatic deliverable imposes on the ALMA construction project is threefold. First, the ALMA software system must be capable of defining a default calibration strategy based on scientific *key values* assigned in advance to each scheduled proposal. This is needed to assure that the pipeline-processed images that go into the ALMA archive are of a consistent and understood quality. Second, the ALMA software system has a firm requirement for a pipeline-processing capability; this was highlighted in section 2 above as a technical deliverable. Further, that pipeline processor must accommodate multiple datasets for the creation of a single image (e.g., observations made with of a single source using two or more array configurations all addressed to a specific scientific goal). Third, the ALMA software system requirement includes provision for a permanent archive that is network-accessible—this involves both an adequate software system and the hardware needed to support the archive.

3.2 Array Operations Facilities and Infrastructure

A primary safety guideline for the ALMA Project is to minimize the number of staff assigned to the 5000 m Array Operations Site (AOS). This guideline has many ramifications that can be summarized by the statement that ALMA will be operated remotely. That is, the array operator and all personnel involved with astronomical observations and maintenance of array instrumentation will be located at ALMA facilities at lower elevation. This leaves on the AOS only those personnel needed to assure the security of the site, people whose task it is to maintain the back end electronics and the correlator at the central electronics building on the array site, those responsible for module exchange—replacing failed instrument modules with functioning spares that are stored on the AOS—and those whose task it is to transport the antennas as needed for array reconfiguration. In order to achieve this goal the entire array must be designed and built to be modular in character, and wherever possible to be self-diagnosing. Each instrument must have provision for an adequate number of monitor points that are reported to the control computer in real time.

The guidelines to minimize the size of the operating staff, maximize the operating effectiveness of that staff, and to minimize the instrumental "downtime" all lead to the Project requirement to locate the operating staff close to the AOS but at lower altitude. Here the considerations are to provide a work environment that is at an elevation where the deleterious effects of a reduced oxygen environment are minimized but nevertheless a work environment that is sufficiently close to the AOS that instrumental problems can be investigated and solved quickly. We refer to this operations and maintenance facility as the Operations Support Facility (OSF). One of the deliverables of the ALMA Construction Project is to connect the OSF to the AOS by means of a road for the transportation of the antennas and operations/maintenance staff, and a communications highway involving buried optical fibers over which the astronomical data and the instrument monitor data is carried in real-time, and at high bandwidth. These links will give the ALMA operations staff a virtual presence on the AOS that will be adequate to investigate problems quickly and begin the process of effecting a cure.

During construction, the antennas will be erected by the antenna contractor at the OSF and, once accepted by the project, they will be carried on the antenna transporter to the AOS. The location for the OSF is ~15 km east of San Pedro and south of the Paso de Jama on land administered by the Chilean Office of National Assets. From this location a restricted-use road will be built connecting the AOS to the OSF in a direct line that can be used not only to transport the assembled antennas to the AOS without using the public highway, but can also be used to return the antennas to the OSF for repair and maintenance. Operationally, only routine antenna maintenance will be performed at 5000 m altitude. All major antenna work will be done at the OSF. The increased proximity of the OSF to the AOS makes it possible at some time in the future to locate the array correlator at the OSF thereby moving still more operations staff off the 5000 m site; this is a decision to be made later in the operational phase of the telescope operational life.

3.3 Construction Project Interface to ALMA Operations: Commissioning and Interim Operations

The sixty-four antenna ALMA array is kept *coherent*, that is, all antennas sample the incoming wavefront from an astronomical source at the same relative phase. This is done by transmitting to each antenna a common local oscillator signal and then delaying processing of the intermediate-frequency data from each antenna according to the instantaneous source-antenna geometry. The data received by each antenna and transmitted to the central array electronics building for processing by the correlator also takes into account the difference in transmission times from each antenna to the central building. Thus, ALMA has some components of its technical baseline that are multiples of 64 (e.g., the antennas, receiving system) and some components of the technical baseline that are individually unique (e.g., the local oscillator generator that serves as the reference for the whole array; the correlator). The array, even with only its first two antennas, cannot function as a scientific instrument without all the unique devices, but it can function with fewer than the full complement of 64 antennas or other equipment modules that are *antenna-based.*

> <u>Interim Science Operations:</u> *It is the fundamental programmatic goal of the ALMA construction project to begin operating ALMA as an interferometric array for scientific research as soon as it is possible to do so: (i) in order make use of experienced scientists to uncover hardware and software problems in the course of doing their research so that such problems are readily identified and it is possible to implement design changes to solve those problems early in the construction project; (ii) to refine array instruments and techniques that depend on actual array site conditions that affect science research programs; (iii) to demonstrate ALMA's science capabilities; and (iv) to gain early operating experience that can be fed back to the construction project and changes can be made to improve reliability or maintainability of the array.*

<u>Requirements for Instrument Priorities and Instrument Commissioning</u>

- The unique, one-off, array instrumentation modules must be given highest priority among construction tasks so that they are completed as early in the project as possible and the interim science operations may commence with the first few antennas in Chile.

- Hardware delivered will be integrated, verified, and *commissioned* subsystem module-by-subsystem module. Once commissioned, each subsystem module will be placed into service in the operating array.

Requirements for ALMA operations derived from the fundamental programmatic goal

- The initial complement of the ALMA operations team must be in place at the OSF and on the array site at the time the first array subsystem modules are commissioned. It will be the responsibility of these operational staff to maintain and operate the commissioned modules.
- Planning for operations and maintenance of the array are an integral part of the ALMA design with the purpose of maximizing efficiency and minimizing cost.
- Early definition of the scientific operations is necessary for software and data management planning and verification. For this reason, the details of scientific operations need to be defined and implemented by the time the first few antennas arrive on site.

Annex B

ANNEX B

ALMA SCIENCE REQUIREMENTS

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The material in this document has not been approved

The Atacama Large Millimeter Array (ALMA) Project will provide scientists with an instrument uniquely capable of producing detailed images of the formation of galaxies, stars, planets, and of the chemical precursors necessary for life itself.

ALMA should provide astronomers a general purpose telescope which they can use to study at high angular resolution millimeter wavelengths emission from all kinds of astronomical sources. ALMA will be an appropriate successor to the present generation of millimeter-wave interferometric arrays and will allow astronomers to:

- Image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z=10;
- Trace through molecular and atomic spectroscopic observations the chemical composition of star-forming gas in galaxies throughout the history of the universe;
- Reveal the kinematics of obscured galactic nuclei and Quasi-Stellar Objects on spatial scales smaller than 300 light-years;
- Assess the influence that chemical and isotopic gradients in galactic disks have on the formation of spiral structure;
- Image gas-rich, heavily obscured regions that are spawning protostars, protoplanets and pre-planetary disks;
- Reveal the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of invisible stellar nuclear processing;
- Obtain unobscured, sub-arcsecond images of cometary nuclei, hundreds of asteroids, Centaurs, and Kuiper-belt objects in the solar system along with images of the planets and their satellites;
- Image solar active regions and investigate the physics of particle acceleration on the surface of the sun.

ALMA is conceived and designed to be a long-lived user observatory. Its scientific impact at any time will be facilitated by the quality of its instruments and limited only by the creativity and industry of its scientist-users.

ALMA will provide the capability to extend the high-resolution imaging techniques of radio astronomy to millimeter and submillimeter wavelengths to achieve an astronomical imaging capability equal in clarity of detail to the imaging capability of the Hubble Space Telescope (HST) and large ground based telescopes. It will do so at wavelengths where the richness of the sky is provided by thermal emission from the cool gas and dust from which stars and all cosmic objects form. In this sense, ALMA is the appropriate scientific complement to the VLT and Gemini, to the HST, and its successor instrument the Next Generation Space Telescope (NGST), instruments which image clearly light from stars and collections of stars such as galaxies.

The primary science requirement for ALMA is the flexibility to support the breadth of scientific investigation to be proposed by its creative scientist-users over the decades long lifetime of the instrument. However, three science requirements stand out in all the science planning for ALMA done in both Europe and in North America. These three level-1 science requirements are the following:

1) The ability to detect spectral line emission from CO, NII or CII in a normal galaxy like the Milky Way at a redshift of z=3 in less than 24 hours of observation.

2) The ability to image the gas kinematics in a solar mass protostar with a protoplanetary disk at the distance of the star-forming clouds in Ophiuchius or Corona Australis, and to detect the tidal gaps created by planets forming in these disks.

3) The ability to provide precise images at an angular resolution comparable with that of optical telescopes or NGST, viz. resolution of order 0.1". The term precise images means images not limited by imaging artifacts at a dynamic range less than 1000:1 over the entire sky visible from the ALMA site.

These requirements drive the concept of ALMA to its current technical specifications. A simplified flowdown of Science Requirements into Technical Specifications is:

1) For high redshift galaxies, the translation of the science requirement into a performance specification can be easily made by comparison with the results obtained by current millimeter arrays, which have collecting areas between 500 and 1000 square meters. These arrays can detect CO emission from the brightest galaxies, amplified by gravitational lensing in one to two days of observations. Signal from normal, unlensed objects, will be typically 20-30 times fainter.

The sensitivity of an array is essentially controlled by 3 major terms: the atmospheric transparency, the noise performance of the detectors, and the total collecting area. Compared to current mm arrays, by locating ALMA on a better site, contribution of the atmosphere will be minimized. The noise level of the detectors cannot be reduced by much more than a factor 2, because these receivers are approaching fundamental quantum limits. Square root 2 will be gained by using both states of polarization. The remaining factor 7-10 can only be gained by increasing the collecting area by a similar amount. Hence, ALMA must be at least 7000 square meters in collecting area.

2) A similar sensitivity argument can also be made for the studies of protoplanetary disks: going from the 0.5" angular resolution obtained in the best images with current mm arrays to the 0.1" resolution comparable with that of optical telescopes requires a factor 25 improvement in sensitivity, similar to that mentioned above.

Gaps created by proto Jupiter-mass planets in protoplanetary disks are expected to be of the order of 1 AU in size. Combined with the distance of the nearest star forming regions, 60--140 pc, this implies ALMA to provide 10 milli-arcsecond resolution or better. This can be obtained by combining high frequency (650 GHz and above) observations with several km size baselines.

3) High fidelity imaging requires a sufficient number of baselines, in order to cover adequately the uv plane. Detailed studies of the imaging performance of aperture synthesis arrays have shown imaging performance implies a minimum number of antennas, 40 or above, and accurate measurements of the shortest baselines, as well as of the large scale emission measured by total power from the antennas. Such accurate measurements can only be obtained with high quality antennas, with superior pointing precision. High fidelity imaging also requires the ability to perform calibrations to “freeze” the atmospheric turbulence which distorts the radiation coming from celestial sources.

The combination of these 3 major requirements calls for a reconfigurable zoom-lens array covering baselines from a few meters up to several kms, observing over the full millimeter and submillimeter atmospheric windows. The maximum size of the individual antennas is driven by the required pointing and surface precision: a choice of 12-m antennas offers an excellent technological compromise. To provide no less than 7000 m^2 of total collecting area, 64 antennas are needed, which is a large enough number to guarantee excellent imaging performance.

Finally, to allow cancellation of atmospheric disturbances, the antennas must be equipped with devices measuring the atmospheric pathlength variations, such as Water Vapor Radiometers (WVR), and be able to detect calibration sources such as quasars in a time short enough to minimize these fluctuations. This requires wide instantaneous bandwidth for the receivers to maximize the continuum sensitivity.

The final major scientific requirement affects the diverse community that will use and benefit from the scientific capabilities that ALMA brings to extend their research endeavors: ALMA should be "easy to use" by novices and experts alike. Astronomers certainly should not need to be experts in aperture synthesis to use ALMA. Automated image processing will be developed and applied to most ALMA data, with only the more intricate experiments requiring expert intervention.

Annex C

ANNEX C

WORK BREAKDOWN STRUCTURE, SCHEDULE OF VALUES AND ASSIGNMENT OF DELIVERABLES

Draft: 4 April 2002

The material in this document has not been approved

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1. WORK BREAKDOWN STRUCTURE

The ALMA Work Breakdown Structure (WBS) is a detailed description of all the tasks necessary to construct the instruments and software required for ALMA; to construct the buildings, roads, antenna foundations, utilities and infrastructure needed for the support of those instruments and software; to integrate the whole into a properly functioning synthesis array telescope on the Chajnantor site in northern Chile; and to manage the construction project on behalf of the two sponsoring ALMA partners.

The ALMA WBS was derived in three steps. First, the scientific requirements for ALMA were specified by the joint North American-European ALMA Science Advisory Committee (ASAC). Second, a technical description of an array capable of meeting those requirements was outlined by the technical leaders of the ALMA Project in North America and Europe. Close and frequent interaction was required between the ASAC and the technical project leadership to assure that the planned technical capabilities met the science requirement priorities. Third, a plan for design and fabrication, or procurement, of all the hardware modules and subsystems was established. Costs were estimated for all tasks and subtasks. The process was informed and constrained by the estimated resources the sponsors were intending to commit to ALMA. The resulting project description was organized into the WBS which specifies in sufficient detail the tasks and the resources, both personnel and financial, required to realize those tasks for the completed project.

The WBS for the ALMA construction project is included below. The WBS is organized into nine level-1 tasks:

1. Management/Administration
2. Site Development
3. Antenna Subsystem
4. Front End Subsystem
5. Back End Subsystem
6. Correlator
7. Computing Subsystem
8. System Engineering and Integration
9. Science

2. SCHEDULE OF VALUES

Costs and contingencies were developed for each subtask of the WBS and rolled up as the summed costs of tasks; the task costs were subsequently rolled up as the summed Project cost. The basis for the cost estimate was a bottom-up sum of the costs associated with each subtask of the Project-wide WBS. The European and North American technical leaders, working together, developed estimates for the entire task product tree using a standard project-supplied *ALMA Cost Data Sheet* that asked the technical leaders to provide for each task:

- Task description;
- Task duration (or start and stop dates and predecessor tasks);
- Currency used for materials, supplies and contract expense;
- Basis of the estimate;
- Contingency;
- Staff Effort;
- List of materials and estimated cost of each;
- List of contracts and estimated cost of each;
- Cost parameterization.

Personnel costs are fully burdened costs. That is, the personnel costs include personnel benefits and a percentage of institutional indirect costs. The institutional indirect cost is a uniform percentage derived from the major partner institutions; this is done to make the personnel cost independent of where the work is performed.

Contingency was separately calculated for each subtask. The contingency methodology used was a *bottom-up* computation of the sum of three separately calculated contingencies. These three contingencies correspond to three different risk factors: the technical risk (how difficult is the task?), the cost risk (what is the uncertainty on the cost?), and the schedule risk (how does this task affect the overall schedule?). Estimators evaluated the technical, cost and schedule risk factors for a particular WBS task and then entered those factors in the ALMA Cost Data Sheets.

The resulting costs and contingencies are shown on the WBS at level-3. Where the costing estimates were made at a lower level, these have been rolled up and displayed at level-3. Three cost columns are shown: the level-3 task cost, computed as described above, the computed task contingency, and the task *value* which is the sum of cost and contingency task-by-task.

3. ASSIGNMENT OF DELIVERABLES

As stated in Article 2 of The Agreement, the two ALMA Parties, North America and ESO, will make equal Value contributions to ALMA with the work equally and equitably shared between North America and ESO. Therefore, using the *values* assigned to level-3 tasks, the tasks were divided between the two Parties in a manner that (a) led to an equal assignment of value to both sides; (b) led to a division of equal risk, as measured by contingency, to both sides; and (c) respected particular institutional experience on both sides. The division of values was also informed by the funding schedules planned by both parties over the ten year duration of the construction project.

The resulting division of value is presented in the WBS for each level-3 task as a percentage division between Europe and North America. A Cost Summary sheet, included with the WBS, presents explicitly this same information rolled up to level-1.

Value: An ALMA Partner executing a particular level-3 task will receive for the successful completion of that task credit for the *value* assigned in the WBS. The Partner has the discretion to carry out the task in the manner the Partner chooses to be in its best interest, but the *value* is not affected by that choice.

Responsibility: Task responsibility is assigned at WBS level-2. This is noted for each task in the final (right-most) column in the WBS. The level-2 tasks are referred to as *work packages* that the responsible partner may wish to assign to one of its participating institutions. Each work package is sub-divided into *work elements*. These are the level-3 tasks to which *value* is assigned. Usually the work elements are assigned wholly to one partner or the other. In the case of shared level-3 tasks the division of effort as 100 percent to one side or another is made at a still lower level. This information is given on the individual ALMA Work Element sheets that are not included here.

Contingency: Contingency is held by the Executives. Although contingency is computed task-by-task, it is accumulated by the Executives and used at the discretion of the Executives to solve problems or execute project options for added science capability.

ALMA Construction Plan Cost Summary

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WBS Task Description	Labor (Staff years)	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin.	83	10,467	1,328	5,085	16,880	5.0%	844	17,724
2 Site Development	43	4,969	314	56,757	62,040	15.4%	9,572	71,612
3 Antenna Subsystem	63	8,890	1,189	190,461	200,539	14.9%	29,877	230,417
4 Front End Subsystem	442	35,901	2,045	55,546	93,492	20.9%	19,567	113,059
5 Back End Subsystem	151	14,220	825	26,467	41,512	23.3%	9,675	51,186
6 Correlator	49	4,460	246	8,637	13,343	13.3%	1,776	15,119
7 Computing Subsystem	230	22,155	2,303	7,129	31,586	15.8%	4,976	36,563
8 System Eng. & Integration	152	14,587	892	3,236	18,716	11.2%	2,097	20,813
9 Science	74	7,447	693	915	9,055	5.0%	453	9,507
Subtotals (Year 2000 US Dollars)	**1,287**	**123,096**	**9,834**	**354,232**	**487,162**	**16.2%**	**78,838**	**566,000**

ALMA Construction Plan Cost Summary Breakdown

North American Tasks

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WBS Task Description	Labor (Staff years)	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin.	42	5,234	664	2,543	8,440	5.0%	422	8,862
2 Site Development	16	1,873	120	21,447	23,441	15.5%	3,630	27,071
3 Antenna Subsystem	31	4,330	582	92,012	96,924	14.9%	14,435	111,360
4 Front End Subsystem	221	18,474	900	24,512	43,886	23.1%	10,122	54,008
5 Back End Subsystem	96	9,234	512	14,259	24,004	19.8%	4,745	28,749
6 Correlator	43	3,909	230	8,537	12,675	13.8%	1,743	14,418
7 Computing Subsystem	115	11,171	1,170	3,564	15,905	15.5%	2,467	18,372
8 System Eng. & Integration	76	7,294	446	1,618	9,358	11.2%	1,048	10,406
9 Science	37	3,724	346	458	4,527	5.0%	226	4,754
Subtotals (Year 2000 US Dollars)	**677**	**65,242**	**4,970**	**168,949**	**239,161**	**16.2%**	**38,839**	**278,000**

ALMA Construction Plan Cost Summary Breakdown

European Tasks

2002 March 12

WBS Task Description	Labor (Staff years	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin.	42	5,234	664	2,543	8,440	5.0%	422	8,862
2 Site Development	27	3,096	193	35,310	38,599	15.4%	5,942	44,540
3 Antenna Subsystem	32	4,559	607	98,448	103,615	14.9%	15,442	119,057
4 Front End Subsystem	221	17,427	1,145	31,034	49,606	19.0%	9,446	59,052
5 Back End Subsystem	55	4,986	314	12,208	17,508	28.2%	4,930	22,438
6 Correlator	6	551	16	100	667	5.0%	33	701
7 Computing Subsystem	115	10,984	1,133	3,564	15,681	16.0%	2,509	18,191
8 System Eng. & Integration	76	7,294	446	1,618	9,358	11.2%	1,048	10,406
9 Science	37	3,724	346	458	4,527	5.0%	226	4,754
Subtotals (Year 2000 US Dollars)	**610**	**57,855**	**4,864**	**185,283**	**248,002**	**16.1%**	**39,998**	**288,000**

Atacama Large Millimeter Array

ALMA Construction Plan 2002-Mar-12.
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
	ALMA Project Plan 2002Mar12			**$566,000**			
1	**Management / Admin.**			**$17,724**			
1.010	Management And Administration			$11,116			IPO
1.010.0100	North American Project Office	5293	265	$5,558	100%		
1.010.0120	European Project Office	5293	265	$5,558		100%	
1.015	International Project Office			$6,609			IPO
1.015.0160	International Project Office	6294	315	$6,609	50%	50%	
2	**Site Development**			**$71,612**			
2.020	Site Construction Management			$4,577			Europe
2.020.0200	Site Development Management	4359	218	$4,577	35%	65%	
2.025	Site Development			$67,035			Europe
2.025.0210	Site Infrastructure	4748	770	$5,519	71%	29%	
2.025.0220	Array Site	29351	4760	$34,111	49%	51%	
2.025.0240	Operations Support Facility (OSF)	14104	2287	$16,391	0%	100%	
2.025.0260	Array/OSF Access Roads	6708	1088	$7,796	33%	67%	
2.025.0280	Array/OSF Communication Links	1823	296	$2,119	100%	0%	
2.025.0300	Chilean Phase 2 Facilities	946	153	$1,099	0%	100%	
3	**Antenna Subsystem**			**$230,417**			
3.030	Antenna Management/Engineering			$5,627			Ant IPT
3.030.0320	Antenna Management Phase 2	3358	168	$3,526	50%	50%	
3.030.0340	Production Antenna Engineering Support	1928	174	$2,102	50%	50%	
3.035	Prototype Antenna Evaluation Support			$2,212			Ant IPT
3.035.0360	North Am. Post Acceptance Evaluation	889	216	$1,106	100%		
3.035.0380	Euro Post Acceptance Evaluation	889	216	$1,106		100%	
3.036	European Prototype Antenna Phase 2			$2,500			Europe
3.036.0410	European Phase 2 Prototype Antenna	2381	119	$2,500		100%	
3.045	Antenna Contract Tendering/Supervision			$2,364			Ant IPT
3.045.0440	Final Design Mods & Documentation; Prepare Bid Package	203	24	$227	50%	50%	
3.045.0460	Production Antenna Contracting	1778	240	$2,018	50%	50%	
3.045.0480	Final Foundation Design	109	10	$119	50%	50%	
3.050	Antenna Procurement			$211,048			Ant IPT
3.050.0500	Production Antennas	183520	27528	$211,048	49%	51%	
3.060	Production Antenna Acceptance at OSF			$2,618			Ant IPT

ALMA Construction Plan 2002-Mar-12.
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
3.060.0560	Production Antenna Acceptance at OSF	2288	330	$2,618	50%	50%	
3.065	Nutator Design/Fabricate			$808			N. Am.
3.065.0580	Production Antenna Nutator	645	163	$808	100%		
3.070	Transporter Design/Fabricate			$3,239			Europe
3.070.0600	Transporter Design / Fabrication	2550	689	$3,239		100%	
4	**Front End Subsystem**			**$113,060**			
4.075	Front End Management/Subsystem Engineering			$6,595			FE IPT
4.075.0620	Front End Subsystem Management	3928	196	$4,124	50%	50%	
4.075.0640	Front End Subsystem Engineering	2353	118	$2,470	50%	50%	
4.080	Cryostat Design/Prototype			$450			Europe
4.080.0660	Cryostat Design/Prototype	311	140	$450		100%	
4.085	Cryostat Production			$12,392			Europe
4.085.0680	Cryostat construction	7364	1194	$8,558		100%	
4.085.0700	Cryocooler	3606	227	$3,834		100%	
4.090	Windows/IR/Common Optics Design/Prototype			$663			Europe
4.090.0720	Windows/IR/Common Optics Design/Prototype	457	206	$663		100%	
4.095	Windows/IR/Common Optics Production			$1,754			Europe
4.095.0740	Common Optics	627	181	$808		100%	
4.095.0760	Windows and IR Filters	766	179	$946		100%	
4.100	Electronics/M&C Design/Prototype			$607			N. Am.
4.100.0780	FE Electronics / M&C Design/Prototype	418	189	$607	100%		
4.105	Electronics/M&C Production			$6,122			N. Am.
4.105.0800	Production Front End Electronics	2347	592	$2,940	100%		
4.105.0820	Front-end IF Selection Switch	1403	278	$1,681	100%		
4.105.0840	Front End Monitor and Control System	1016	485	$1,501	100%		
4.110	FE Subreflector Calibration System Development			$985			N. Am.
4.110.0860	Photonic Phase Cal Development	684	302	$985	100%		
4.115	FE Focal Plane Calibration System Development			$344			Europe
4.115.0880	Calibration System Development	287	57	$344		100%	
4.120	FE Subreflector Calibration System Production			$4,727			N. Am.
4.120.0900	Photonic Phase Cal Production	2724	1203	$3,927	100%		
4.120.0940	Subreflector Calibration System - control s/w and h/w	255	46	$301	100%		
4.120.0960	Subreflector Calibration System - hardware at subreflector	451	49	$500	100%		

ALMA Construction Plan 2002-Mar-12.
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.125	FE Focal Plane Calibration System Production			$1,830			Europe
4.125.0920	Calibration System	872	173	$1,045		100%	
4.125.0980	Solar Filter	665	120	$785		100%	
4.140	Band 3 Cartridge Design/ Prototype			$481			N. Am.
4.140.1003	Band 3 Cartridge Design / Development	331	149	$481	100%		
4.145	Band 3 Cartridge Production			$9,799			N. Am.
4.145.1063	Signal and LO Sources Band 3	155	19	$174	100%		
4.145.1080	Band 3 SIS Mixer	750	351	$1,102	100%		
4.145.1103	LO Production Band 3	1281	300	$1,581	100%		
4.145.1123	SIS Mixer Production Equipment Band 3	657	83	$740	100%		
4.145.1140	IF amplifier 4-12 GHz (Band 3 SIS option only)	534	67	$602	100%		
4.145.1163	Build SIS mixer fabrication equipment Band 3	293	37	$330	100%		
4.145.1180	Band 3 - SIS mixer option: Other components	3586	646	$4,232	100%		
4.145.1203	Cartridge Body construction Band 3	161	26	$187		100%	
4.145.1303	Cartridge test cryostat Band 3	0	0	$0		100%	
4.145.1403	SIS Junctions Band 3	780	70	$851	100%		
4.160	Band 6 Cartridge Design/ Prototype			$488			N. Am.
4.160.1006	Band 6 Cartridge Design / Development	336	151	$488	100%		
4.165	Band 6 Cartridge Production			$11,335			N. Am.
4.165.1066	Signal and LO Sources Band 6	180	23	$203	100%		
4.165.1106	LO Production Band 6	1415	357	$1,772	100%		
4.165.3106	LO Production Diode Multipliers Band 6	305	77	$381	100%		
4.165.1126	SIS Mixer Production Equipment Band 6	657	83	$740	100%		
4.165.1166	Build SIS mixer fabrication equipment Band 6	287	36	$323	100%		
4.165.1206	Cartridge Body construction Band 6	161	26	$187		100%	
4.165.1240	Band 6 SIS Mixer	750	351	$1,102	100%		
4.165.1260	Production Band 6 Orthomode Transducer (OMT)	902	512	$1,414	100%		
4.165.1280	14 IF amplifier 4-12 GHz (Band 6 only)	534	67	$602	100%		
4.165.1306	Cartridge test cryostat Band 6	0	0	$0		100%	
4.165.1320	Band 6 Other components	3187	574	$3,762	100%		
4.165.1406	SIS Junctions Band 6	780	70	$851	100%		
4.170	Band 7 Cartridge Design/ Prototype			$544			Europe
4.170.1007	Band 7 Cartridge Design / Development	375	169	$544		100%	

Atacama
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ALMA Construction Plan 2002-Mar-12

All Tasks selected

All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.175	Band 7 Cartridge Production			$11,631			Europe
4.175.1107	LO Production Band 7	1415	357	$1,772	100%		
4.175.3107	LO Production Diode Multipliers Band 7	305	77	$381	100%		
4.175.1207	Cartridge Body construction Band 7	161	26	$187		100%	
4.175.1307	Cartridge test cryostat Band 7	0	0	$0		100%	
4.175.1340	Band 7 Internal optics, feed & polarizer baseline	390	98	$488		100%	
4.175.1360	Band 7 SIS Mixer baseline	1258	589	$1,847		100%	
4.175.1407	SIS Junctions Band 7	780	70	$851		100%	
4.175.1420	Band 7 Other Components baseline	4876	1230	$6,106		100%	
4.190	Band 9 Cartridge Design/ Prototype			$601			Europe
4.190.1009	Band 9 Cartridge Design / Development	414	187	$601		100%	
4.195	Band 9 Cartridge Production			$14,278			Europe
4.195.1109	LO Production Band 9	1415	357	$1,772	100%		
4.195.3109	LO Production Diode Multipliers Band 9	305	77	$381	100%		
4.195.1209	Cartridge Body construction Band 9	161	26	$187		100%	
4.195.1309	Cartridge test cryostat Band 9	0	0	$0		100%	
4.195.1409	SIS Junctions Band 9	780	70	$851		100%	
4.195.1460	Band 9 cartridge parts (excl. mixer)	4781	1120	$5,901		100%	
4.195.1480	Band 9 fabrication equipment Part 1	663	66	$729		100%	
4.195.1500	Band 9 fabrication equipment Part 2	328	32	$360		100%	
4.195.1520	Band 9 mixer	2790	1307	$4,098		100%	
4.210	WVR Radiometer Design/ Prototype			$311			Europe
4.210.1011	WVR Cartridge Design / Development	214	97	$311		100%	
4.215	WVR Radiometer Production			$7,869			Europe
4.215.1560	183GHz WVR Production, Installation & Commissioning	7219	650	$7,869		100%	
4.220	Integration Test Facilities Develop/Procure			$1,338			N. Am.
4.220.1580	Front End Test Station Development	1116	221	$1,338	100%		
4.225	Integration Test Facilities Duplicate			$775			Europe
4.225.1600	Front End Test Station Replication	711	64	$775		100%	
4.230	Frontend Integration			$9,886			N. Am.
4.230.1620	Front End Integration Center #1 Setup and Operation	4183	754	$4,937	100%		
4.230.1630	Front End Integration Center #2 Setup and Operation	4193	756	$4,949		100%	
4.235	Front End Mechanical Chasis/Mount			$1,078			N. Am.

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.235.1660	Front End Chassis	748	330	$1,078	50%	50%	
4.240	Front End Service Vehicle			$674			N. Am.
4.240.1680	Front End Service and Exchange Vehicle	599	76	$674	100%		
4.245	Photonic LO Development			$1,515			N. Am.
4.245.1700	Photonic LO Development N. Am.	721	36	$758	100%		
4.245.1705	Photonic LO Development Europe	721	36	$758		100%	
4.250	LO Driver Development			$1,083			N. Am.
4.250.1720	LO driver continued development section	407	95	$503	100%		
4.250.1740	Cold multiplier continued development section	492	89	$580	100%		
4.255	Multiplier/Driver Production			$2,905			N. Am.
4.255.1760	LO Multiplier Drivers fabrication and test	1871	438	$2,309	100%		
4.255.1800	Cold multiplier fabrication and test equipment	542	54	$595	100%		
5	**Back End Subsystem**			**$51,186**			
5.260	Back End Management Subsystem Engineering			$3,190			BE IPT
5.260.1880	Backend Mgmt/Subsystem Engineering Phase 2	2200	110	$2,310	75%	25%	
5.260.1840	LO Ref Engineering Field Support	372	34	$406	100%		
5.260.1860	Photonic Dist Engineering Support	256	23	$279	100%		
5.260.1900	Backend Engineering Support	186	9	$196	67%	33%	
5.265	Back End Analog Processing Design/Prototype			$729			N. Am.
5.265.1920	Prototype System IF Down-converter	599	130	$729	100%		
5.270	Back End Analog Processing Production			$9,529			N. Am.
5.270.1940	IF Down-converter	7323	1319	$8,642	100%		
5.270.1960	Power Supply Modules	405	20	$426	100%		
5.270.1980	BE Production Test & Lab Equipment	416	45	$461	100%		
5.275	Back End Digitizer Design/Prototype			$1,316			Europe
5.275.2000	Backend Digitizer/Sampler Prototype	1051	265	$1,316		100%	
5.280	Back End Digitizer Production			$4,277			Europe
5.280.2020	Digitizer/Sampler	2101	530	$2,631		100%	
5.280.2040	DeMultiplexer for Digitizer/Sampler	1260	386	$1,646		100%	
5.285	Back End Data Transmission Design/Prototype			$879			N. Am.
5.285.2060	Prototype System Digital IF Tx & Rx	745	134	$879	50%	50%	
5.290	Back End Data Transmission Production			$15,598			N. Am.
5.290.2080	Sampler Clock	759	137	$896		100%	

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
5.290.2100	Digital IF Transmitters and Receivers	11101	3601	$14,702	25%	75%	
5.295	LO Frequency Synthesis Design/Prototype			$1,078			N. Am.
5.295.2120	LO Reference Prototype	778	140	$918	100%		
5.295.2140	FO Transmitter, LO Ref - Low Freq	127	32	$159	100%		
5.300	LO Frequency Synthesis Production			$13,217			N. Am.
5.300.2160	FO Receiver, LO Reference	1615	407	$2,022	100%		
5.300.2180	Two-Laser generator, RF synthesizer	353	38	$391	100%		
5.300.2200	Second LO Synthesizer	3981	861	$4,842	70%	30%	
5.300.2220	Fringe Generator	309	56	$365	100%		
5.300.2240	Central LO Reference Generator	101	11	$112	100%		
5.300.2260	H-maser Frequency Standard	386	70	$456		100%	
5.300.2280	Power Supply Modules	462	23	$485	100%		
5.300.2300	LO Ref Production supervision & int.	679	86	$765	100%		
5.300.2320	LO Ref Production test & lab equipment	270	24	$294	100%		
5.300.2335	Photonic Dist Prototype	784	212	$996	100%		
5.300.2340	Fabricate Photonic Dist Production System	1795	695	$2,490	50%	50%	
5.305	Back End Installation/Integration in Chile			$1,374			BE IPT
5.305.2360	LO Reference On Site Integration and Test	346	87	$434	50%	50%	
5.305.2380	Photonic Dist On Site Integration and Test	405	102	$507	50%	50%	
5.305.2400	Backend On Site Integration and Test	346	87	$434	50%	50%	
6	**Correlator**			**$15,119**			
6.310	Correlator Management/Subsystem Engineering			$909			Corr IPT
6.310.2420	Baseline Correlator Mgmt/Subsystem Engineering Phase 2	453	23	$475	100%		
6.310.2440	Baseline Correlator Continued Support	397	36	$433	100%		
6.315	Baseline Correlator Design/Prototype			$924			N. Am.
6.315.2460	Prototype Correlator Production	738	186	$924	100%		
6.320	Baseline Correlator Production			$12,586			N. Am.
6.320.2480	First 1/4 correlator	2749	372	$3,121	100%		
6.320.2500	Second 1/4 correlator	2744	371	$3,115	100%		
6.320.2520	Third 1/4 correlator	2744	371	$3,115	100%		
6.320.2540	Fourth 1/4 correlator	2850	385	$3,235	100%		
6.325	Second Generation Correlator Design/Prototype			$701			Europe
6.325.2570	Second Generation Correlator Development	667	33	$701		100%	

Atacama
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ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
7	**Computing Subsystem**			**$36,563**			
7.340	Computing			$36,563			Com IPT
7.340.2640	Computer Subsystem Management	2534	127	$2,660	63%	38%	
7.340.2660	Computing Hardware	7129	899	$8,028	50%	50%	
7.340.2680	Science Software Requirements	820	148	$967	44%	56%	
7.340.2700	High Level Analysis & Design	461	83	$544	44%	56%	
7.340.2720	Software Engineering	1947	351	$2,297	42%	58%	
7.340.2740	Common Software	2408	434	$2,841	43%	57%	
7.340.2750	Executive Software	307	55	$363		100%	
7.340.2760	Control Software	2459	443	$2,902	81%	19%	
7.340.2780	Correlator Software	1537	277	$1,814	100%		
7.340.2800	Pipeline Software	1742	314	$2,055	65%	35%	
7.340.2820	Archiving	1742	314	$2,055	24%	76%	
7.340.2840	Scheduling	512	92	$605	100%		
7.340.2860	Observing Preparation & Support	1639	295	$1,935		100%	
7.340.2880	Off-line Data Processing/Analysis	1537	277	$1,814	70%	30%	
7.340.2890	Data Reduction User Interface	717	129	$846		100%	
7.340.2900	Telescope Calibration	922	166	$1,088		100%	
7.340.2920	Integration, Test & Support	3176	572	$3,748	53%	47%	
8	**System Eng. & Integration**			**$20,813**			
8.360	System Engineering Management			$2,351			Sys IPT
8.360.2940	SE&I Management	2239	112	$2,351	50%	50%	
8.365	System Engineering Development Support			$8,275			Sys IPT
8.365.2960	Phase 2 System Engineering	7591	684	$8,275	50%	50%	
8.370	Test Interferometer Support			$2,721			Sys IPT
8.370.2980	ALMA Prototype Antenna Evaluation	1804	260	$2,064	50%	50%	
8.370.3000	Prototype ALMA System Integration	556	100	$656	50%	50%	
8.375	System Validation, Integration, Acceptance			$7,466			Sys IPT
8.375.3020	ALMA System Integration	6525	941	$7,466	50%	50%	
9	**Science**			**$9,507**			
9.380	Science			$9,507			Sci IPT
9.380.3040	Phase 2 Science Support	9055	453	$9,507	50%	50%	

Annex D

ANNEX D

ALMA PROJECT TIME SCHEDULE

Draft: 4 April 2002

The material in this document has not been approved

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1 Overview

The schedule for the ALMA construction project is determined by (1) the availability of resources to support the work necessary to complete Project tasks, and the effort supported by those resources required for each of the tasks, and (2) by the ability of the Project management to minimize *latency* between serially-dependent tasks by making timely decisions.

2 Resource Availability

The plans being made by the NSF and by ESO for funding the ALMA construction project are different. The two funding profiles described as "resource plans" are presented in Table 1. It should be noted that the North American resources represent annual commitment authority whereas the European resources represent annual expenditures corresponding to the different financial procedures and regulations applicable to the NSF and ESO. Particularly for contracted tasks, the expenditure profile normally lags the commitment profile by a substantial amount. The NSF is planning to fund the project beginning in 2002 by quickly ramping up the funding to a level near $40 million per year and then ramp it down again in the last two years. ESO on the other hand, plans to fund the project more slowly initially with a continuous ramp up of the funding throughout a period that is two years longer than the NSF funding plan.

The mechanism used to mesh the funding plans with the project tasking, and hence to organize the project schedule, is to assign responsibility for the early project tasks preferentially to North America whereas responsibility for tasks that come at the end of the project are preferentially assigned to Europe. It is possible to achieve such a division, but not without the consequence of extending the construction project by an additional year beyond that originally planned by the NSF in which the spending is largely European.

Table 1. ALMA Construction Project Resource Availability

Estimated Resources: Millions of Year 2000 U.S. Dollars		
Fiscal Year	**North America**	**Europe**
2002	11.7	10.1
2003	27.0	13.3
2004	43.5	16.4
2005	41.3	25.4
2006	39.2	27.9
2007	37.1	32.2
2008	34.8	32.2
2009	27.0	32.2
2010	14.65	32.2
2011		32.2
2012		32.15
Total	**$276.25**	**$286.25**

Note: North American resources represent annual commitment authority; European resources represent annual expenditures.

ALMA Construction Schedule: Selected Milestones

(Merged North American and European Constraints)

Date	Milestone or Deliverable		Note
Jul-02	Deliver VertexRSI Prototype Antenna to ALMA Test Facility at the VLA Site; Tests Begin		
Aug-02	Project Begins Negotiation with VertexRSI for Firm, Fixed-Price, Procurement of Production Antennas as Stated in the Prototype Antenna RFP		*Prices Solicited for Quantities of 32 and 64 Antennas. Prices to be Valid for 12 Months.*
Jan-03	Site Access Permissions Secure; Begin Site A&E Studies		
Feb-03	Receive VertexRSI Price for Production Antennas		*Clocks Starts on 12 month Validity of VertexRSI Price Quote*
Apr-03	Preliminary Assessment Report of VertexRSI Antenna Conformance with Project Specifications		
Apr-03	Deliver A/C/E Prototype Antenna to ALMA Test Facility at the VLA Site; Tests Begin		
Apr-03	**Project Decision Point: 15 April 2003**		***<u>Fixed date.</u>*** *Project can decide whether to award the production antenna contract to VertexRSI for all 64 antennas. Decision to be based on whether the measured performance meets ALMA specifications and whether the price quote is within the project cost envelope.*
Apr-03	**Project Decision:** To Recommend Award of Contract for Procurement of VertexRSI Antennas. Project Negotiation Process with VertexRSI Begins	**Project Decision:** To Proceed with Competitive Procurement Process; Defer recommendation of Award of Contract for Procurement of VertexRSI Antennas <u>at this time</u>	*Dependent consequence of the Project decision*
May-03		Issue Open RFP (CfT) for Production Antennas	*Project RFP. Issued to All Interested Bidders; Open Competition. Bidders Given CDD Material for both VertexRSI and A/C/E Antennas*
Oct-03	Begin Initial Phase of Site Construction	Begin Initial Phase of Site Construction	
Jan-04	Sign Production Antenna Contract		
Jan-04		Preliminary Assessment Report of A/C/E Antenna Conformance with Project Specifications	
Jan-04		Proposal Due Date; Evaluation Begins	
Jan-04		Reassess Whether to Award Contract for Procurement of VertexRSI Antennas at this time. <u>This is a Fixed Project Milestone Date.</u>	*Clock Runs out on Validity of VertexRSI Price Quote (from Feb 2003)*
Jan-04		**Project Decision:** Begin Process to Award Contract for Procurement of Antennas from Vendor Chosen by the Competitive Procurement	*Decision input includes comparison on VertexRSI price with prices received from open competition.*

Mar-04		Select Vendor; Begin Negotiation with Vendor	
Jul-04			
Sep-04		Recommend Award of Contract for Procurement of Production Antennas to Selected Vendor. Contract Approval Process Begins	
Dec-04		Sign Production Antenna Contract	
Mar-05	Receive First Production Antenna in Chile (at the OSF)		
Sep-05			
Oct-05	Finish Initial Phase of Site Construction	Finish Initial Phase of Site Construction	
Nov-05	Deliver first quadrant of correlator to Chile (capability for 32 antennas at full bandwidth	Deliver first quadrant of correlator to Chile (capability for 32 antennas at full bandwidth	
Dec-05		Receive First Production Antenna in Chile (at the OSF)	
Mar-06	Start of Science Commissioning Observations		*Limited Capabilities; Observations for Engineering Purposes*
Mar-06			
Sep-06			*Limited Capabilities; Observations for Engineering Purposes*
Dec-06		Start of Science Commissioning Observations	*Limited Capabilities; Observations for Engineering Purposes*
Mar-07	Start of Interim Science Operations		*Competitive Proposals; Limited Capabilities and Availability*
Sep-07			*Competitive Proposals; Limited Capabilities and Availability*
Dec-07		Start of Interim Science Operations	*Competitive Proposals; Limited Capabilities and Availability*
Nov-08	Correlator Delivery to Chile Complete (all four quadrants; capability for 64 antennas at full bandwidth	Correlator Delivery to Chile Complete (all four quadrants; capability for 64 antennas at full bandwidth	
Dec-11	Completion of Construction Project	Completion of Construction Project	

Explanatory Note to the ACC Regarding the ALMA Project Schedule(not part of Annex D)

A. The Antenna Procurement Process

The Dual Prototype Antenna Strategy: Risk Management

At the time that the joint US-European Design and Development phase for ALMA was defined, it was agreed that both the US and Europe would each procure a prototype antenna. This would be done on the basis of independent contracts to different vendors with the technical specifications and delivery schedule for each being identical. The motivation for such an approach was to reduce risk to the Project in the area of greatest financial exposure, namely for the production quantity of 64 antennas. There are three areas of risk: technical, cost and schedule.

- Technical risk: Can an antenna contractor build an antenna that meets the demanding ALMA requirements?
- Cost risk: In large quantities, will the antenna contractor build the antennas to specifications, delivered in Chile, at a cost that the Project can afford?
- Schedule risk: Does the antenna contractor have the management and corporate organization sufficient to give us confidence that they can meet the Project antenna delivery schedule?

With two antenna contractors working on the same prototyping task we believed that the Project had adequately addressed the risks by doubling the chance that one or another, or both of the contractors, would meet the ALMA specifications with their prototype.

The Dual Prototype Antenna Realities

Both prototype antennas were scheduled for delivery to the ALMA Test Facility at the VLA site at the end of calendar year 2001. The delivery date for both antennas slipped. Presently, the VertexRSI prototype antenna procured by AUI has a delivery slated for June 2002 giving an achieved delivery of 27 months. The EIE contract, supported by ESO, was restructured to include Alcatel as the primary partner; the Alcatel delivery is slated for April 2003 giving an earliest delivery of 36 months. The nine or ten month difference in these delivery dates removes the chance for a contemporaneous evaluation of the two prototypes. But the goal of the prototype antenna procurement remains unchanged, namely to demonstrate that the major risk areas in the procurement of the ALMA production antennas are reduced to a manageable level.

B. A Project Time Schedule that Respects Resource Availability and Minimizes Risk of Delays in the Antenna Procurement Process

As noted above, it is possible to organize the Project WBS to accommodate the planned funding schedules of the two ALMA partners. This leaves procurement of the ALMA production antennas as the critical path task for the ALMA construction project, and this is the task for which latency is a risk. The ALMA time schedule presented below as a series of critical project milestone delivery dates, addresses this issue.

The Project Schedule calls for a project decision in April 2003 as to whether to proceed with a contract with VertexRSI for the 64 ALMA antennas. April 2003 is the date at which we will know whether the VertexRSI antenna meets the technical specifications, and VertexRSI will have provided a binding cost for 64 antennas at that time. We will also have clear knowledge as to the delivery status of the Alcatel antenna at the same time. This is enough information to make an informed decision. If the VertexRSI antenna does not meet the technical requirements, or if the cost for the 64 antennas provided by VertexRSI is outside the Project cost envelope, then the competitive bid process (open to all vendors, not just Alcatel and VertexRSI) that is the alternative plan to be followed. This introduces a delay of nearly a year (and the risk that it could be more) in the antenna procurement task.

The key to minimizing the prospect for delay is to emphasize that the ALMA Project does not need *the best* antenna that can be built; it needs an antenna that meets the Project specifications and can be produced at a cost that is affordable by the Project. Getting to this point was the whole purpose of building prototype antennas. Once we have clear indication from measurements made on a prototype antenna, and discussions with the vendor, that a prototype satisfies these requirements, it is in the best interest of the Project and its sponsors to contract for that antenna without delay. Doing so will not only get what is needed by the Project but it will remove the risk from the antenna procurement task at the earliest possible date. In addition to delivery of the antennas, one of the largest challenges for early science operations lies in the timely delivery of the front ends.

C. Inconsistency Between Resources and Current Cost Estimates

Appendix C indicates a current cost estimate of $566.00 (Y2000). This is $3.5M above the total resources of $562.5 indicated in Table 1 of Appendix D. This additional cost includes increasing the duration of the project through the end of CY2011. The estimated cost impact of the additional year has been minimized by assuming that most construction activities have been completed within the original duration. A minimum staff will be required to integrate the already completed ALMA hardware with the final antennas delivered in CY2011. Realizing this level of increase will require most ALMA staff to be off of the construction budget by the end of 2010.

Annex I

ANNEX I

ALMA ORGANIZATION AND MANAGEMENT PLAN

Draft: 4 April 2002

The material in this document has not been approved

Table of Contents

1 MANAGEMENT STRUCTURE

1.1. Overview of the ALMA Management Structure

The management structure of the ALMA Project is chosen to assure that the goals of the project are met. In the case of ALMA, these goals extend beyond the usual project goals of control of performance, cost, and schedule. For a partnership of equals, the appropriate management structure must be consistent with the additional guiding principles of parity and equity as described in Article 2 of the ALMA Agreement. These principles set forth a project where work is carried out through two Executive bodies rather than in a single organizational entity. This separation of effort calls for a project organization in which work is managed and coordinated jointly while resources are allocated separately.

The entities that create the ALMA Project are the *Parties*. The Parties are the entities that provide funding for the project. The Parties have two initial responsibilities: (1) to establish jointly, and by agreement, an oversight body for the Project, the *ALMA Board*; and (2) independently to appoint an *Executive Agency,* or *Executive*, to manage the project tasks and responsibilities that are agreed to become the purview of each Party. The ALMA Board is not a legal entity, but the Executives are legal entities (i.e., they can enter into contracts, employ staff, etc). In order to carry out their ALMA functions each of the Executives will create an *ALMA Project Office* and secure for that office the staff and resources necessary for the performance of the ALMA tasks assigned to that Executive. The ALMA Board, on the other hand, has the responsibility to establish an *International Project Office* (IPO) that will manage the ALMA Project. The IPO will carry out its management function by specifying the scope, schedule and tasks of the Project and then coordinating the efforts of the Executives to provide the necessary deliverables.

Figure 1 illustrates the development of this management structure. The development begins on the left with the Parties establishing the ALMA Board and appointing Executives. Subsequently, the Executives create their respective Project Offices. The ALMA Board establishes the International Project Office and appoints the ALMA

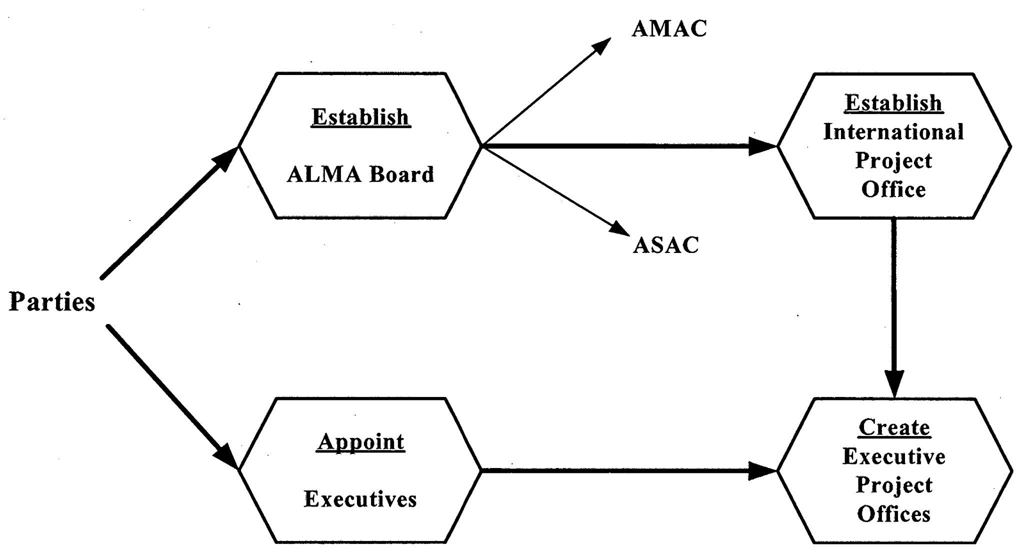

Figure 1. Development of the ALMA Project Management Structure

Science Advisory Committee (ASAC) and the ALMA Management Advisory Committee (AMAC).

The management structure needed for the bilateral ALMA Project is one capable of assuring that the usual project goals of cost, performance, and schedule compliance are achieved. But in addition, the guiding principles make it clear that it must also be one in which the work can be done by the Executive Agencies making use of the staff and resources of those Executives. The principle that no new institution is to be established as an organizational entity for ALMA means that the project must be organized so that the work is managed and coordinated jointly, but resources are allocated separately. It is a significant challenge to create a management structure that satisfies all these requirements. The nature of the ALMA Project as the production of a set of tightly integrated instrumentation assemblies makes it impossible to separate the project into two or three independent parts that can be simply controlled by two or three global interface documents; a tightly integrated management is necessary for a tightly integrated project.

As a solution to this problem, the management structure for the ALMA Project is based on the concept of *Integrated Product Teams* (IPTs). The essence of the IPT concept is the recognition that often the level-1 WBS tasks are shared between the two Executives; for this reason the leadership for those level-1 tasks are also shared. The IPT is that shared leadership. Each IPT consists of all those individuals who are assigned by one or another of the Executives with significant responsibility for subtasks within a given level-1 WBS task. The IPT staff will not be co-located; each individual works within the infrastructure of his or her Executive. The leadership of each IPT is provided by the Executives' respective task leaders. One of these persons will be identified as the IPT Leader and the other will serve as the IPT Deputy Leader. The intent is that these individuals will normally resolve by consensus any technical issues that arise within the IPT.

The IPT Leader and the Deputy are vested with the responsibility to assign, coordinate and monitor subtasks as specified by the ALMA WBS. In practice, this means that each of these individuals is responsible for completing the assigned subtasks within the existing infrastructure of, and using the resources provided by, their respective Executives.

The IPT management structure is a powerful method of organizing work carried out across geographic, institutional, and professional boundaries. It allows work packages assigned to different organizations utilizing different skill sets to be effectively coordinated. The IPT model is adopted for the ALMA Project to achieve the following goals:

- Provide a single point of integrative responsibility for each major work package. A single individual, the IPT Leader, is identified for each IPT. This Leader is responsible for assuring that the various work packages, when completed, will meet the project schedule and the performance specifications.
- Provide common, coordinated, management of the IPT and the work groups within the Executives. The IPT Leader and the Deputy are themselves the work managers for the Executives. Common management provides the link between the project coordination function and the means to accomplish the work within the Executives.
- Make decisions at the lowest level in the organization where sufficient knowledge is available. The organizational and technical complexity of the ALMA Project makes it impossible for all significant decisions to be deliberated project-wide. Instead,

responsibility will be delegated to the IPTs and will carry with it authority to make decisions within that particular IPT. This has the benefit of empowering all those individuals who have responsibility for ALMA tasks and subtasks.

The Management IPT differs functionally from the other IPTs. The composition of the Management IPT is the Project Managers from the Executives, just as is the case for the other IPTs with their managers, with the addition of the ALMA Project Director and Project Manager, who are on the staff of the IPO. Within the Management IPT, the Project Managers from each of the Executives function as deputies to the ALMA Project Manager. The individual Project Managers from each of the Executives report to their respective Executive; the ALMA Project Director and Project Manager, as part of the IPO staff, report to the ALMA Board.

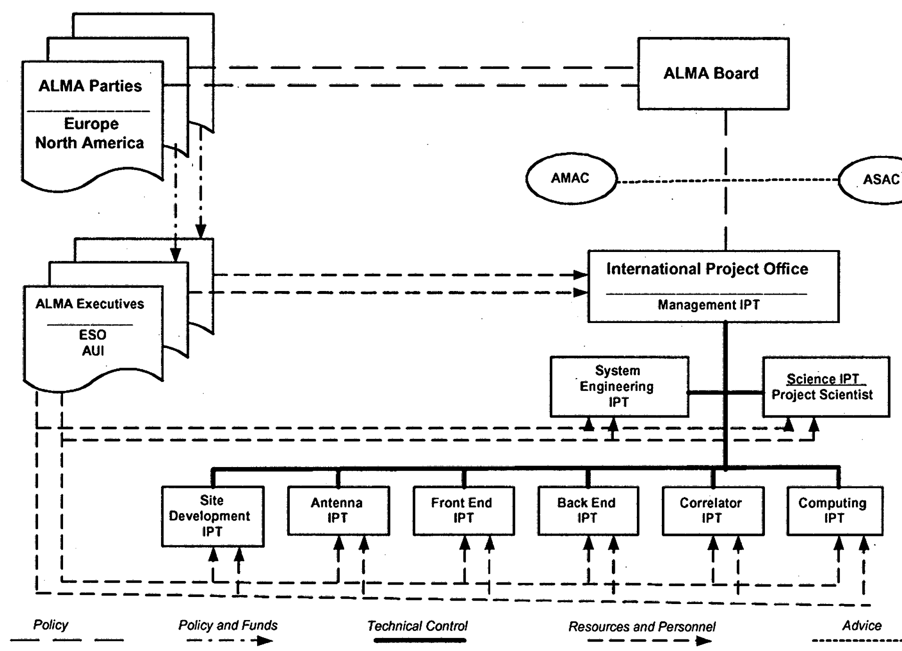

Figure 2. ALMA Project Management Structure - Construction Phase

The ALMA Project management implementation, structured around effort being the responsibility of the Executives but organized as IPTs, is illustrated in Figure 2. By focusing on the right side of this diagram, one can see that the ALMA Project has a traditional hierarchical management structure. In particular, the ALMA Board serves the function of a board of directors, the IPO functions as the project management, and the IPTs function as task managers. The unusual aspect of the management structure proposed for ALMA is the execution of tasks, or shares of tasks, at the Executives.

The functional structure of the ALMA Project is shown schematically in Figure 3. The ALMA management functions along the lines of a general contractor with the IPO serving as that general contractor. Specifically, the IPO provides to the Executives a detailed definition of the ALMA system structured as a set of *work packages*. The Executives each agree to perform those work packages as the equivalent of *fixed price contracts*. The IPO then monitors those contracts and coordinates the interaction among the work package deliverables. However, it is not the intention that the IPO funds those contracts. Instead, the Executives receive their funding directly from their respective Parties and the Parties in turn receive project credit for the "value" of the work package deliverables as agreed with the IPO.

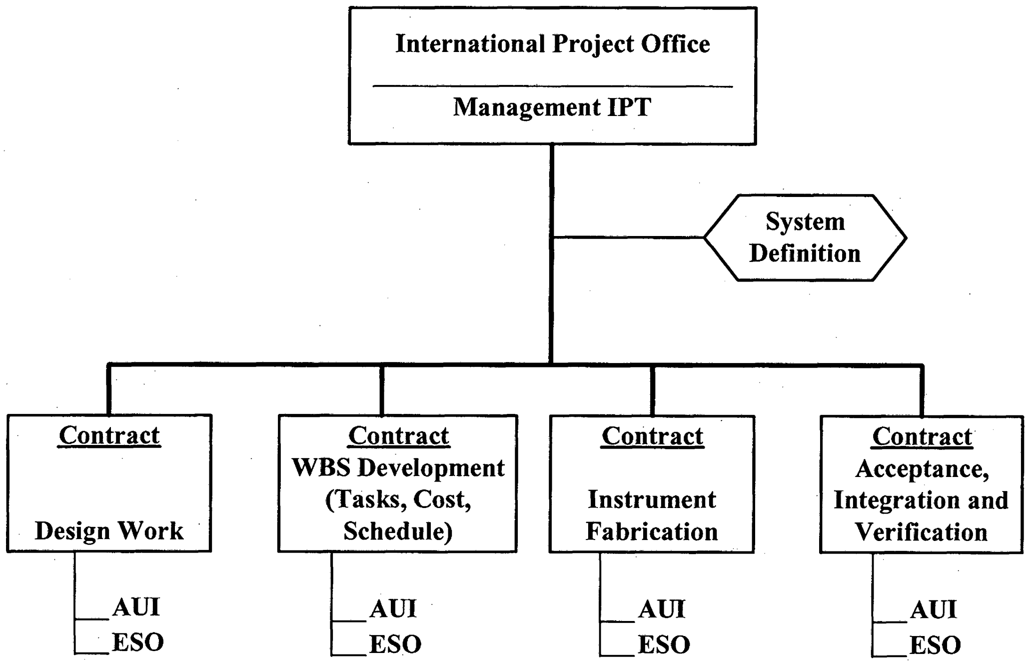

Figure 3. Functional Outline of ALMA Project Management

1.2. Role of the International Project Office (IPO)

Whether thought of functionally as the ALMA general contractor, or thought of structurally as the ALMA central management, the International Project Office is the focal point for implementation of the proposed ALMA Management Plan.

Project Scope and Schedule: The IPO will:

- Define and maintain the top-level scientific requirements and scope of the project. This is done through a negotiation involving the user communities (as represented by the ASAC) and the ALMA Board. It is a tradeoff between prioritized science goals and costs.
- Establish the requirements for the ALMA system. Working in conjunction with the IPT Leaders and Deputies, the IPO establishes the technical specifications corresponding to the top-level scientific requirements. Work packages will be developed to those specifications that will enable the IPO to negotiate with the Executives for completion of those work packages to a particular cost or "value." The IPO will serve as the ALMA "customer"; the Executives are "vendors."
- Establish and maintain the Project WBS and Schedule. This is the core of the management task for ALMA. It is the WBS and schedule that ties the efforts of the Executives together.

- Establish and control the configuration. This means enforcing strict adherence to the specifications and the WBS. Where the specifications or WBS must be changed, those changes have to be managed centrally. It is the IPO that controls the change process and manages the consequences of a change.
- Define, maintain and enforce Interface Control—indispensable for a project done by many institutions working cooperatively.

Costs: The IPO will:

- Provide an impartial, and consistent, accounting of the costs. This applies both to the cost of the baseline project and the cost of any additions or proposed alternatives. This prevents the Executives from being their own arbiter of costs.
- Negotiate an adjustment of "valued" cost estimates in the face of experience where necessary. This is to handle the case where, for some external reason, the cost of a particular task varies substantially above the value previously fixed for it. Such an event will have consequences for all Executives, not just the one with the task facing such a change.
- Serve as "scorekeeper" to assure that the valued contributions of each Executive remain on a par with those of the other. This is to handle the case where the action, or inaction, of one Executive causes a cost increase for the other. An example would be the failure of one Executive to deliver a subassembly to the other Executive on schedule causing the second Executive to idle some part of his workforce. The IPO will negotiate an equitable adjustment in credited value.

Accountability: The IPO will:

- Establish and enforce acceptance criteria for delivered hardware and software from the two Executives.
- Be accountable to the ALMA Board for management of the Project.
- Be accountable to the ALMA Board in achieving its scientific goals in accordance with the advice of the ASAC.

1.3. Composition of the IPO

The IPO will be composed of the following professional staff that report exclusively to the ALMA Board:

- Project Director
- Project Manager
- Project Engineer*
- Project Scientist*

** Potential key personnel in the IPO – still under discussion.*

In addition, the IPO will employ a project controller/scheduler(s) to be responsible for the WBS and the necessary reporting. Administrative staff will provide supporting functions. The staff of the IPO should be co-located. With approval of the ALMA Board, each member of the IPO will be employed by one of the Executives.

1.4. North American ALMA Project Office

ALMA work packages assigned to North America will be the responsibility of the North American ALMA Project Office, which will be part of the North American Executive (NRAO). The ALMA Project will be integrated into the NRAO organizational structure to maximize the benefit of shared resources and infrastructure with other observatory functions. The North American ALMA Project Manager will also serve as a NRAO Assistant Director and report to the NRAO Director. Working through the project IPT structure, the North American Project Manager will be assisted by ALMA Division Heads within NRAO, each of whom have the responsibility for tasks within a given level-1 WBS. The Division Heads will act either as the IPT Leader or Deputy in the corresponding IPTs. The North American Project Office will hold the pooled contingency for all of the North American work packages. Use of this contingency will be coordinated with the International Project Office as described in Section 2.3.

1.5. European ALMA Project Office

The work packages assigned to Europe will be the responsibility of the European Executive (ESO). These work packages will be carried out in existing institutions across Europe, including ESO. This activity will be funded through and co-ordinated by the European ALMA Project Office that will be part of ESO. The European ALMA Project Manager will lead the European Project Office that will be responsible for ensuring that the resources are made available to carry out the European work packages to performance and schedule. Each work package will be covered by a formal agreement between the institution concerned and ESO. The European Project Office will hold the pooled contingency for all of the European work packages. Use of this contingency will again be coordinated with the International Project Office. Working through the project IPT structure, the European Project Manager will be assisted by European Team Managers drawn from the participating institutions. The European Team Managers will have the responsibility for tasks within a given level-1 WBS and will act either as the IPT Leader or Deputy in the corresponding IPT.

1.6. ALMA Scientific Advisory Committee

The ALMA Board will establish an ALMA Science Advisory Committee (ASAC) that will provide regular scientific oversight and advice to the project through reporting to the ALMA Board and through direct interaction with the project organization. The ALMA Board, in consultation with the Executives, will define the terms of reference of the ASAC and appoint its members. The makeup of the ASAC will be an equal number of members each from North America and Europe. The terms of reference will provide that the ASAC will select a chair, who will serve for a period not exceeding one year, from among its members. The chair will alternate between a member from North America and a member from Europe. Following the practice established in Phase 1, it is expected that the ASAC will have one or two face-to-face meetings per year and monthly teleconferences. At each meeting the ASAC will receive reports on the progress and activities from the project scientists and project management as well as any other matters of relevance to the scientific performance of the array. Written reports of the ASAC's discussions will be made to the ALMA Board by the chair of the ASAC following each face-to-face committee meeting.

1.7. ALMA Management Advisory Committee

The ALMA Board will also establish an ALMA Management Advisory Committee (AMAC) that will provide regular management, cost, and technical oversight and advice to the project through reporting to the ALMA Board and through direct interaction with the project management (see Section 2.7). The ALMA Board, in consultation with the Executives, will define the terms of reference of the AMAC and appoint its members. The makeup of the AMAC will be five members each from North America and Europe. The terms of reference will provide that the AMAC will select a chair, who will serve for a period not exceeding one year, from among its members. The chair will alternate between a member from North America and a member from Europe. It is expected that the AMAC will meet at least twice per year. At each meeting the AMAC will receive and review reports on the progress and activities from the project management, as well as a detailed statement on the past and planned use of financial and staff resources. Written reports of these reviews and assessments will be made to the ALMA Board by the chair of the AMAC following each committee meeting.

2. MANAGEMENT CONTROLS

As described in Section 1, management control in the ALMA Project flows through two paths. The joint project organization exercises technical control, starting from the Management IPT and continuing down through the level-1 IPTs to the work packages. Technical control means control over all technical aspects of the project, including performance, and control over schedule. The two Executives, through their respective project offices, allocate resources and control costs. As members of the Management IPT, the European and North American Project Managers also have a role in technical control of the project and conversely, enable the Management IPT to monitor the status of resource allocations and costs on each side.

2.1. Budget Process

The value of each work package in the WBS is the estimated cost plus a contingency that reflects the risks and uncertainty of the estimated cost. The budgeted value of each work package will be established as the estimated cost at the outset of Phase 2, exclusive of any contingency. A time-phased budget based on this value, broken down into the major categories of expenditure (labor, materials, travel, contracts, etc.), will be established and documented for each work package. The Work Package Manager must request approval of any changes to this budget. Documented requests for budget changes will be directed to the Project Manager of the responsible Executive. The responsible Executive Project Manager can approve the budget change request, if it can be absorbed within the overall budget, including contingency, of the responsible Executive. The Management IPT must be informed of any budget change that is so approved. If the resulting change in the overall budget exceeds 1,000,000 U.S. dollars or Euros, and the responsible Executive wants to request a corresponding change in the value of its contribution, the change must be submitted to the ALMA Board for approval.

2.2. Cost Control

Primary responsibility for cost control rests with each Executive. Each Executive will use their established financial reporting and information system to track expenditures and provide this information to the central Management IPT. At the lowest level the Work Package Managers regularly monitor expenditures versus the budget (expenditure plan). Financial information comes either from the responsible Executive or the financial reporting and information system of the institution responsible for the work package, as appropriate. In addition, the Work Package Manager produces an estimated cost to complete the work at least twice per year. The Project Manager of the responsible Executive monitors regularly the cost performance of the aggregate of work packages for which s/he is responsible and reports the status to the Management IPT. The Management IPT in turn monitors the total project cost performance and reports it to the ALMA Board in semi-annual reports and meetings. However, responsibility for taking corrective action and/or requesting a budget change rests with the responsible Executive.

2.3. Contingency

On each side the aggregate contingency of all of the work packages for which each Executive is responsible will be pooled at the level of the Executive. The contingency will be held and controlled by the Project Managers of each Executive. When a Work Package Manager is convinced that it is impossible to complete the tasks in the work package for the budgeted cost, the Work Package Manager will request a budget change allocating contingency to increase the budget for the work package. The Project Manager of the responsible Executive will decide whether to approve or not approve allocation of contingency. If the Project Manager approves the budget change request and allocation of contingency, the Management IPT will be informed of the change. If a Work Package Manager is convinced that the tasks in the work package can be completed for less than the budgeted cost, the Work Package Manager will request a budget change that decreases the budget for the work package and allocates the savings to the contingency pool.

2.4. Business Procedures

Each Executive will use their established business and administrative procedures. These include personnel policies and procedures, contracting and contract management procedures, accounting and financial reporting procedures, travel policies and procedures, and shipping/import/export procedures. Because it is not a legal entity, the International Project Office will not need many of these procedures. Those business procedures that it does need can be adopted from either of the Executives, as the International Project Office chooses.

2.5. Schedule Control

Each Work Package Manager will develop and maintain a schedule of activities for their work package. Each IPT will build up a level-1 schedule of the activities for which it is responsible from the schedules for each of its work packages. The Management IPT will establish and maintain a project master schedule based on the level-1 IPT schedules. Schedule status will be reported up through the project organization – from work packages to IPTs to the Management IPT. The Project Managers for each Executive will get schedule status through the Management IPT.

2.6. Management Reporting

The Work Package Managers will receive monthly reports of the financial status of their work packages from the responsible Executive and provide a monthly report of technical, schedule, and financial status to the relevant IPT. The IPTs will conduct monthly reviews of the status of the work packages for which they are responsible and provide a report to the Management IPT. The Management IPT, through the Project Managers of the Executives, will provide quarterly status reports to the Executives. The Project Director will provide a semi-annual report of the project status to the ALMA Board.

2.7. Programmatic Reviews

The IPT monthly reviews referred to in Section 2.6 will be informal programmatic reviews at the working level. In addition, the Project Director will conduct a formal semi-annual programmatic review of the entire project. Each IPT, including the Management IPT, will present the technical, schedule, and financial status of the work packages for which they are responsible. The financial status will include the current estimated cost to complete. These reviews will be attended by members of the IPTs plus the ALMA Management Advisory Committee (AMAC). The AMAC will meet with the project management immediately following the programmatic review to discuss and advise the project on issues arising from the review. The semi-annual report from the Project Director to the ALMA Board will follow from the semi-annual Director's programmatic review. The AMAC will provide an independent report to the ALMA Board based on their observations at the programmatic review and the subsequent discussions with project management.

2.8. Configuration Control

A well-defined and organized process for controlling and communicating changes throughout the complex and geographically diverse project is essential. Configuration control processes ensure that changes proposed are accepted only after their impacts are well understood and that all parts of the project are aware of changes in a timely manner. A Project process involving a Configuration Control Board is used to control changes affecting scope, schedule and performance. Changes that result in "collateral costs," those costs incurred by one Executive arising from configuration changes requested by the other Executive, are controlled by a process requiring involvement of the ALMA Project Director, the Executives, and the ALMA Board.

2.8.1. The ALMA Configuration

The term "ALMA configuration" refers to all those documents that define the Project. For the purpose of configuration control, the ALMA documents are divided into four groups:

i) Board level documents
i) Project level documents
ii) IPT level documents
iii) Non-controlled documents.

2.8.2. Configuration Control

Configuration control acts on the documents that define the project. The process that is used depends on the type of document, above, that is to be controlled.

Configuration control is made up of four main elements:

i) A means of formally requesting a change; A process for analyzing the technical, performance and schedule impacts of the proposed change;
ii) A process for making a decision concerning the change;
iii) A process for communicating that decision.

The application of these elements to each of the four types of Project documents is as follows.

Board level documents include this Management Plan, official cost and task division documents, the top-level Science Requirements Document, and international agreements passed by the ALMA Board. Baselining of, and changes to, Board level documents can be requested by Board members and require direct action by the ALMA Board; it is the responsibility of the ALMA Project Director to implement changes approved by the Board.

Project level documents include the Project Book, top level engineering requirements documents for each major subsystem and ICDs between subsystems that cross IPT or WBS boundaries. Requests to change project level documents can be initiated by any of the work package or work element managers and require action by the Configuration Control Board (CCB).

IPT level documents include detailed drawings and documents intended to implement the contents of project level documents. Control of these documents is the purview of the IPT management. It is the responsibility of the IPT management to ensure that these documents are consistent with all applicable Project level documents.

Non-controlled documents include the ALMA Memo Series and other documents that do not officially define the Project. Baseline and change authorization for these documents depends on the document type but all such processes are outside CCB control.

The ALMA Project Manager defines which documents are Project level documents and s/he determines when a version of each document is to be submitted to the CCB for baselining. Once baselined, all change requests must be presented to the CCB using the process outlined below.

2.8.3. Configuration Control Board (CCB)

The configuration control board is responsible for managing changes to all project level documents. The CCB is chaired by the ALMA Project Manager. The System Engineering IPT Leader will serve as the CCB Secretary.

In addition to the ALMA Project Manager, the CCB shall consist of six permanent members:

- The Project Managers from both Executives;
- Leader and Deputy Leader of the Science IPT;
- Leader and Deputy Leader of the Systems Engineering IPT.

Additional temporary CCB members may be added at the discretion of the CCB Chair when s/he feels that a particular issue needs special consultation. In any case, as noted below, the CCB solicits input from all IPTs prior to considering a requested change. It is anticipated that most actions will be carried out by consensus of the CCB membership. If efforts to reach consensus fail, a vote of the members will be necessary. Such votes of the CCB can be carried out in any manner selected by the Chair including, but not limited to: face-to-face meetings; audio or video teleconference; email or paper correspondence; or telephone polling.

The ALMA Director has the authority to rescind actions of the CCB by informing the ALMA Project Manager and the ALMA Board.

2.8.4. Change Requests (CR)

A change request (CR) may be made by any of the work package or work element managers. Requests are made in writing using the CR template form available on the ALMA website. All change requests are submitted to the CCB Secretary.

The CR form identifies the initiator and it includes a title, summary, description of the change being proposed, justification and known impacts in the areas of technical specification, science performance and schedule. Detailed information related to the proposed change can be included as attached documents or by reference to existing ALMA documents. The CCB Secretary will assign a CR tracking number, distribute the request to all IPTs and solicit responses as noted below. Cost impact is not an issue for the IPT Leaders to consider directly (see Section 4.8.6).

The systems engineering IPT will assist each IPT as it considers all potential impacts on their respective subsystems. Each IPT Leader is required to submit a response that emphasizes the impacts on his/her subsystem and a judgment as to whether the CR should be approved. Systems engineering will collate the responses and generate a summary for further consideration.

If in the course of consideration of a CR it is necessary to amend the CR itself, the original CR is closed with a disposition of "Withdrawn" and a new CR is initiated that references the previous one. CRs shall not be modified to prevent the possibility of confusion over the definition of a change.

A database of all CRs and their status or disposition will be maintained as part of the official project documentation.

2.8.5. Disposition of Change Requests (CR)

The CCB Secretary will initiate action on the CR depending on his/her assessment of whether the CR is a minor impact on the Project, or a major impact on the Project.

<u>CR with a Minor Impact.</u> The CCB Secretary may categorize the CR as a *Minor CR* if, in his/her opinion, the CR has an engineering impact only. That is, the proposed change to the configuration does not affect science performance, scope, or schedule. The decision process for Minor CRs is the responsibility of the Systems Engineering IPT. In arriving at a decision, the CCB Secretary shall consult with other members of the Project and may, at his/her discretion, seek formal advice or guidance from other IPTs.

Once a decision on the CR is made, the CCB Secretary will initiate the following actions:

i) *If the decision is to deny the CR, the CR will be archived, the IPT Leaders and CCB members will be informed, and no further action will occur.*

ii) *If the decision is to accept the CR, then the CCB Secretary will inform the two Executive Project Managers and seek their written assessment of the cost implications of the proposed change (see Section 4.8.6). S/he will assure that these assessments are forwarded to the ALMA Project Director for approval*

iii) *Once approval of the ALMA Project Director is secured, the CCB Secretary will:*
   a. *Implement the requested change;*
   b. *Archive the CR and its disposition;*
   c. *Inform the IPT Leaders and CCB members of the decision.*

iv) *If the CCB Secretary cannot reach a decision on the CR the issue will be forwarded to the CCB for resolution.*

CR with a Major Effect. The CCB Secretary may categorize the CR as a *Major CR* if, in his/her opinion, the CR will affect science performance, Project scope, or schedule. The decision process for Major CRs is the responsibility of the CCB. The CCB Chair will circulate the CR to all Project IPT Leaders, asking those Leaders for comments. The comments may include advice from other members of the Project, or from outside advisors; each IPT Leader has the discretion to decide what advice is sought, and what comments s/he will write in response to the proposed CR. The CCB will not act until the CCB Chair has received either a comment, or a written statement of "no comment" from each IPT Leader.

Once a decision on the CR is made by the CCB (formally the decision is made by the CCB Chair), the CCB Chair will initiate the following actions:

i) *If the decision is to deny the CR, the CR will be archived, the IPT Leaders will be informed, and no further action will occur.*

ii) *If the decision is to accept the CR then the CCB Chair will inform the two Executive Project Managers and seek their written assessment of the cost implications of the proposed change (see Section 4.8.6). S/he will assure that these assessments are forwarded to the ALMA Project Director for approval.*

iii) *Once approval of the ALMA Project Director is secured, the CCB Chair will:*
   a. *Implement the change requested by making the appropriate changes to the WBS;*
   b. *Archive the CR and its disposition;*
   c. *Provide a written report to the ALMA Project Director on the CR and its effect on the Project scope, schedule and performance.*

iv) *If the CCB cannot reach a decision on the CR, the issue will be appealed to the ALMA Project Director for resolution.*

2.8.6. Control of "Collateral Costs" Resulting from Requested Changes to the ALMA Configuration

The budgetary authority for all of the ALMA Work Elements that make up the scope of the ALMA Project is held either by the European Executive or by the North American Executive. When a request is made to change the ALMA configuration that change may have cost implications to one or both of the Executives. The process used to control these incremental costs is the following:

The two Executive Project Managers will be asked to provide a written assessment of the cost implications of each CR. This applies to both Minor CRs and Major CRs.

i) *For CRs initiated by an ALMA staff member from Executive A that affect work elements that are wholly the responsibility of Executive A, the Project Manager from Executive A may simply inform the CCB Chair (for Major CRs) or the System Engineering Leader (for Minor CRs) that s/he is prepared to accept the cost implications of the CR without providing a quantitative assessment of the cost implication. The Project Manager from Executive B, in this case, must provide either a statement that the CR has no cost impact on Executive B, or s/he must provide a quantitative assessment of the "collateral cost" impact of that CR. Costs incurred by one Executive resulting from CRs initiated by the other Executive we refer to as "collateral costs". In the event that one or both of the Executive Project Managers claim a collateral cost resulting from the CR, the statements of the two Executive Project Managers will be forwarded by the CCB Chair (for Major CRs) or the System Engineering Leader (for Minor CRs) to the ALMA Project Manager for approval.*

ii) *For CRs that affect work elements that are the responsibility of both Executives, both Executive Project Managers must provide statements to the CCB Chair (for Major CRs) or the Systems Engineering Leader (for Minor CRs) that include a quantitative assessment of the cost impact of that CR. The statements of the two Executive Project Managers will be forwarded by the CCB Chair (for Major CRs) or the System Engineering Leader (for Minor CRs) to the ALMA Project Manager for approval.*

iii) *CRs that are initiated by an ALMA staff member from Executive A that affect work elements that are wholly the responsibility of Executive B are handled in the manner described in (ii) above.*

The ALMA Project Manager shall review the cost impact statements submitted by the Executive Project Managers. If the Executive Project Managers agree that there is no cost impact, the ALMA Project Manager will authorize the CCB Secretary (for Minor CRs) or the CCB Chair (for Major CRs) to implement the CR. If the statement from one or both of the Executive Project Managers includes a collateral cost impact, the ALMA Project Manager shall provide an impartial quantitative assessment of the extent to which such impact will be allowed as an adjustment to the value of the affected work package(s) for each Executive. The assessment of the ALMA Project Manager will be delivered to the Executive Project Managers for comment.

- If the Executive Project Managers both agree with the ALMA Project Manager's assessment they shall indicate so in writing to the ALMA Director. In the case that the cost impact of the CR to one or both Executives exceeds 1,000,000 (U.S. dollars or Euros) the ALMA Director will then inform the ALMA Board of the agreed change to the value of the affected work element(s) and seek Board approval for the change in value. The Board may accept, reject, or modify the change. Failure of the Board to act on the matter within 60 days from the date the Board Secretary receives the CR from the ALMA Director shall be regarded as approval. With Board approval, the Director will authorize the CCB Chair or the CCB Secretary, as appropriate, to proceed. In the event the cost impact of the CR is less than 1,000,000 (U.S. dollars or Euros) the Project Director will inform the ALMA Board; Board approval is not required.

- If one or both of the Executive Project Managers disagree with the ALMA Project Manager's assessment they shall indicate so in writing to the ALMA Director. The ALMA Director will review the comments and seek to obtain agreement.
- If no agreement is possible, the ALMA Director shall refer the issue to the ALMA Board for resolution providing the Board with a recommendation as to how the issue should be settled. That recommendation may include rejection of the CR itself. The decision of the Board is final; it is the responsibility of the Project Director to implement that decision.

3. SAFETY AND HEALTH

The ALMA construction activities will take place at existing organizations (e.g., NRAO, ESO, including Chilean operations, and other European and North American institutions) with established safety and health policies and regulations that comply with applicable national or international requirements. The ALMA Project will abide by these established policies and will only create new rules and regulations if no applicable rules and regulations exist. The persons responsible for safety and health management at the participating organizations will report the results of any relevant safety and health audits or reviews to the ALMA Director. Members of the ALMA project staff will serve on safety and health committees at their respective locations.

The ALMA site at 5000-meter altitude in Chile presents unique safety and health challenges. The ALMA Project will abide by all applicable safety and health rules and regulations imposed by Chile. Until the applicable Chilean rules and regulations have been defined in the course of the negotiations to obtain the necessary permissions for construction and operation of ALMA, "Safety Rules for ALMA Personnel on the ALMA 5000-m Site" will be applied.